

Initial results from the HARP experiment at CERN

J.J. Gomez-Cadenas ^{a *}

^aIFIC and Departamento de Fisica, Atómica y Nuclear,
P.O. Box 22085, E-46071 Valencia, Spain

Initial results on particle yields obtained by the HARP experiment are presented. The measurements correspond to proton–nucleus collisions at beam energies of 12.9 GeV/c and for a thin Al target of 5% interaction length. The angular range considered is between 10 and 250 $mrad$. This results are the first step in the upcoming measurement of the forward production cross-section for the same target and beam energy, relevant for the calculation of the far-to-near ratio of the K2K experiment.

1. Introduction

The HARP experiment[1] was designed to perform a systematic and precise study of hadron production for beam momenta between 1.5 and 15 GeV/c and target nuclei ranging from hydrogen to lead. The detector was located at CERN, in the PS beam. The DAQ recorded 420 million events during the years 2001 and 2002.

The physics program of HARP includes: a) the measurement of pion yields for a variety of energies and targets relevant for the design of the proton driver of a future neutrino factory[2]; b) the measurement of pion yields on low Z targets as well as on cryogenic oxygen and helium targets, useful to improve the precision of atmospheric neutrino flux calculations[3]; and c) the measurement of pion and kaon yields, relevant for the calculation of the neutrino fluxes of experiments such as MiniBooNE[4] and K2K[5].

HARP (Fig. 1) is a large acceptance spectrometer, with two distinct regions. In the forward part of the apparatus (up to polar angles of about 250 $mrad$), the main tracking devices are a set of large drift chambers. Magnetic analysis is provided by a 0.4 T dipole magnet and particle identification relies in the combination of a threshold Cherenkov detector, a time-of-flight wall and an electromagnetic calorimeter. In the rest of the

solid angle the main tracking device is a TPC, which is complemented by a set of RPC detectors for time-of-flight measurements. The target is located inside the TPC. In addition, sophisticated beam instrumentation (including three timing detectors and threshold Cherenkov detectors) provides identification of the incoming particle and allows the interaction time at the target to be measured.

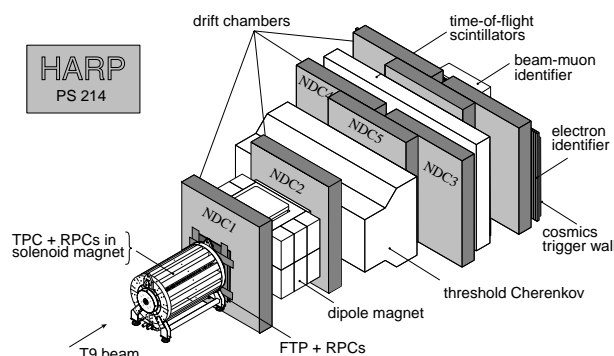


Figure 1. Schematic layout of the HARP spectrometer.

*This work has been supported in part by research grants from Spanish Ministry of Science and Generalitat Valenciana

Given the immediate interest of the MiniBooNE and K2K experiments in a measurement

of the production cross sections for pions and kaons at the energies and targets relevant for their beam setups, the HARP collaboration has given priority to the analysis of those particular data sets. In particular, we present in this article an initial result relevant for the K2K experiment. Specifically, we measure pion yields from proton-nucleus collisions, for a thin Al target (5λ) and a beam energy of 12.9 GeV . The K2K neutrino beam is produced from the decay of hadrons (primarily pions) emanating from a 2λ Al target, at the KEK PS proton driver energies of 12.9 GeV . Further details about the motivation of this analysis can be found in Ref. [6].

2. Forward Tracking and Particle Identification

2.1. Tracking

Tracking of forward-going particles is done by a set of large drift chambers(NDC) placed upstream and downstream of the dipole magnet. The chambers were recuperated from the NOMAD experiment and their properties have been described elsewhere[7]. Each NDC module is made of four chambers, and each chamber of three planes of wires with tilted angles -5° , 0° and 5° . The single-wire efficiency is of the order of 80%, and the spatial resolution approximately $340\text{ }\mu\text{m}$. The performance of the NDC is inferior to the one measured in NOMAD, where the hit efficiency was close to 95% and the resolution approached $150\text{ }\mu\text{m}$. This is mainly due to the fact that, for HARP, the NDC used a gas mixture and voltage settings different from the ones in NOMAD².

Due to the low hit efficiency, the algorithm used in NOMAD, based in building up space points (with an efficiency of about $.95^3 = 85\%$) is not viable (for Harp we would obtain $.80^3 = 51\%$). Instead, the reconstruction builds $2D$ and $3D$ track segments in each NDC module (12 hits maximum), which are fitted to a straight line model via a Kalman Filter fit[9].

Next, the algorithm attempts all possible combinations (which include at least a $3D$ segment) to connect tracking objects in the modules down-

stream of the dipole magnet. Combinations such as $3D + 2D$ or even $3D + \text{hits-not-associated}$ are valid ways to build longer, $3D$ segments.

To measure the momentum it is necessary to connect a ($3D$) segment downstream of the dipole with at least one space point upstream of the dipole. Since one can impose the constraint that all tracks emanate from the event vertex³this point is always known and therefore the necessary and sufficient condition for a particle emanating from the target to have its momentum measured is that a $3D$ segment can be measured by the combination of downstream NDC chambers.

A measurement in the first NDC module is not strictly necessary to analyse the track momentum. Ideally, one would like, of course, to connect a $3D$ segment downstream with a $3D$ segment in the NDC1 and the vertex point. However, the tracking efficiency of the upstream module is sizeable lower than the efficiency of the downstream modules. This is due to, a) a higher hit density in NDC1⁴ and b) the lack of redundance due to the fact that there is only a single module upstream of the dipole. A too restrictive condition to accept a track such as matching a $3D$ segment upstream of the dipole with a $3D$ segment downstream results not only in lower efficiency, but also in a systematic error, arising from the uncertainties in the hit density expected in NDC1 which would be hard to estimate (hit density depends on factors such as track multiplicity and opening angle, which are model-dependent). Instead, by building a track *always* when a $3D$ segment is present downstream of the dipole, one is practically independent of the tracking efficiency in NDC1.

In order to quantify these considerations, we have considered three different types of tracks, depending on the matching between the downstream and upstream modules. Type I is a $3D$ - $3D$ matching. Type II matches a $3D$ (downstream) with a $2D$ (upstream). Type III are those where one has been unable to find either a $3D$ or a $2D$

³for a thin target the vertex is known with a precision of about 1 cm In the case of thick target, a vertex algorithm will provide the event vertex to a comparable precision.

⁴the hit density decreases quadratically with the distance to the vertex, and therefore the effect is only significant for NDC1.

² $Ar(90\%)-CO_2(9\%)-CH_4(1\%)$, a non-flammable gas mixture.

segment in NDC1 and thus the track is built using the downstream modules and the vertex constraint.

2.2. Particle Identification

Particle identification (PID) in the forward region of the spectrometer combines the information provided by beam detectors and three systems located downstream the dipole magnet. Namely, a threshold Cherenkov detector (CKOV), a time-of-flight wall (TOF), and an electromagnetic calorimeter (electron identifier, EID). These subsystems have been described in Ref. [6]. Its combined information results in good PID over the whole range of relevant momenta, as well as redundancy due to overlaps. Pion/proton separation is provided by TOF up to 4.5 GeV/c , and by the CKOV above 3 GeV/c . Electron/pion separation is covered by the CKOV below 3 GeV/c and by the EID above 2 GeV/c . Finally the kaon contamination can be estimated with the CKOV above 3 GeV/c and with the (TOF) below this energy.

3. The analysis

About one sixth (1 million events) of the “K2K thin target” data has been analysed. The unnormalised pion production differential cross section can be computed as follows:

$$\sigma_i^\pi = \frac{1}{\varepsilon_i^{acc}} \frac{1}{\varepsilon_i^{track}} \sum_{t=1}^3 \left[M_{ij}^{(t)} \frac{1}{\varepsilon_j^{(t)-\pi}} \eta_j^{(t)-\pi} \cdot N_j^{(t)-\pi} \right] \quad (1)$$

where the sum runs over track types (I = 3D-3D, II= 3D-2D, III=3D-vertex) and the indices i and j correspond to true and reconstructed (p, θ) bins respectively. ε_i^{acc} is the geometrical acceptance, ε_i^{track} is the tracking efficiency, M_{ij} is the migration matrix from reconstructed bin j to true bin i , ε_j^π is the pion identification efficiency, η_j^π is the pion purity and N_j^π is the observed pion yield. The pion purity is defined as $\eta_j^\pi = N_j^{true-\pi} / N_j^\pi = (N_j^\pi - N_j^{bkg}) / N_j^\pi$, where $N_j^{true-\pi}$ is the number of true observed pions in the bin j , and N_j^{bkg} is the number of particles misidentified as pions in the same bin j . That means that η_j^π is just the probability of correct

identification of a pion. The pion identification efficiency, ε_j^π is the fraction of times that a tracked pion is identified as such.

Fig. 2 shows the spectrometer acceptance. For clarity of illustration, the momentum acceptance has been computed in the region of good angular acceptance, ($|\theta_y| < 50 \text{ mrad}$, $|\theta_x| < 200 \text{ mrad}$) and conversely, the geometrical acceptance has been computed in the region of good momentum acceptance ($P > 1 \text{ GeV}$). As it can be seen the acceptance is good for pion momenta above 1 GeV/c , and still acceptable above 0.5 GeV . As illustrated in Ref. [6] this permits the measurement of K2K neutrino fluxes up to 0.25 GeV , which amply covers the energy region where the atmospheric oscillation affects the neutrino spectrum maximally. The angular acceptance is also very well matched to K2K physics requirement.

The tracking efficiency is shown in Fig. 3 as a function of p and θ_x . The contributions of track types I,II and III are normalized individually, so that the total efficiency is the sum of the three. Notice that the loss in efficiency at low polar angles for tracks of type I (due to saturation effects in NDC1) is largely compensated by tracks of type II and III, so that the total tracking efficiency is rather flat.

Finally, the yield must be corrected by the pion efficiency and purity, which is computed from the data themselves, using samples of pions, protons electrons and kaons of various energies tagged with the help of the beam detectors. The pion correction factor defined as the ratio of purity over efficiency is shown in Fig. 4, for the three track types and for 1.5, 3 and 5 GeV beam particles.

Preliminary studies show an almost diagonal migration matrix, where migration is mainly due to finite momentum and angular resolutions, but not to systematic effects (momentum and angular biases, etc).

Figure 5 shows the pion yields as a function of momentum after successive corrections (e.g., acceptance, tracking efficiency and pion correction factor). No attempt to deconvolute the data (e.g., correct for migrations) have been done yet, and no absolute normalization is computed.

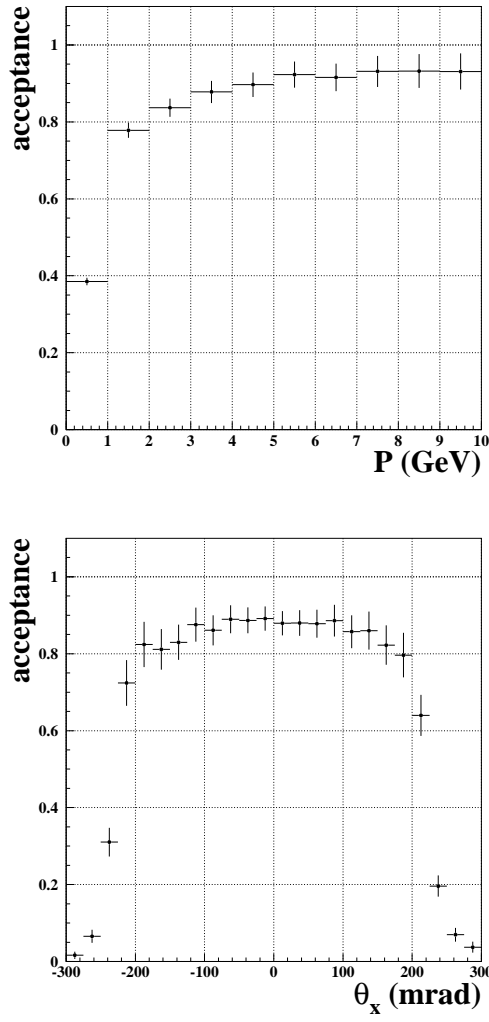


Figure 2. Acceptance in P for $|\theta_y| < 50 \text{ mrad}$, $|\theta_x| < 200 \text{ mrad}$. Acceptance in θ_x for $|\theta_y| < 50 \text{ mrad}$ and $P > 1 \text{ GeV}$

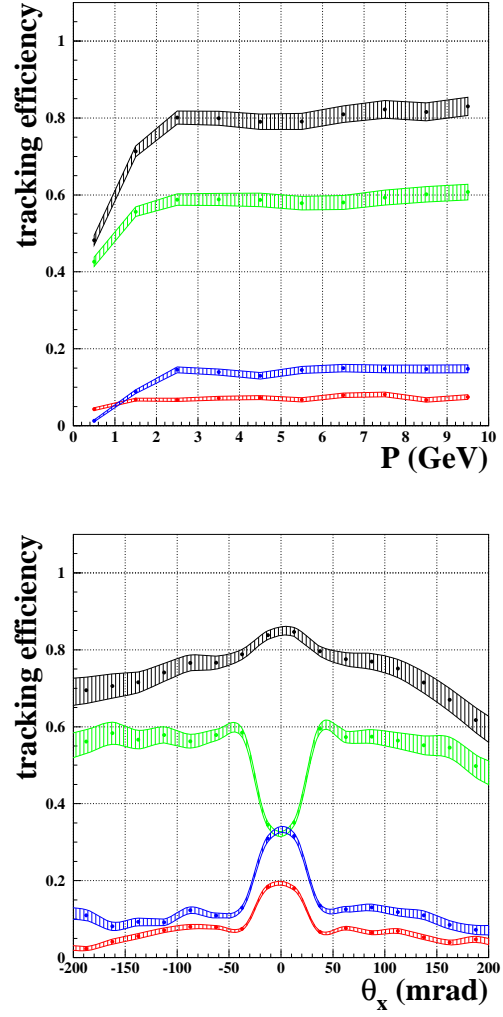


Figure 3. Tracking efficiency as a function of p (left) and θ_x (right). The colors indicate: black=total, green=type I, red=type II, blue=type III.

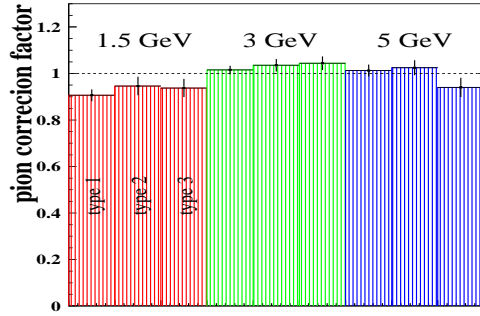


Figure 4. Pion correction factor. The colors indicate: red=1.5GeV, green=3GeV, blue=5GeV

4. Conclusions

We have presented a preliminary analysis of one of HARP data samples, corresponding to a thin Al target, at beam energies of 12.9 GeV. This analysis is relevant for the K2K experiment and a first step towards an upcoming measurement of the fully corrected production cross section.

REFERENCES

1. The HARP Collaboration, CERN-SPSC/2003-027, SPSC-P-325
2. For a recent review of the neutrino factory see, for example J.J. Gomez-Cadenas and D.A. Harris, Ann.Rev.Nucl.Part.Sci.52:253-302,2002e
3. See for example G.D. Barr et al., Phys.Rev.D70:023006,2004.
4. See for example A. Aguilar-Arevalo hep-ex/0408074, J.L. Raaf, hep-ex/0408008.
5. M.H. Ahn *et al.*, The K2K Collaboration *Phys. Rev. Lett.* **490**, 041801 (2003).
M.H. Ahn *et al.*, The K2K Collaboration *Phys. Lett. B* **511**, 178 (2001).
6. A. Cervera Villanueva, hep-ex/0406053. Proceedings of 39th Rencontres de Moriond on QCD and High-Energy Hadronic Interactions, La Thuile, Italy, 28 Mar - 4 Apr 2004.

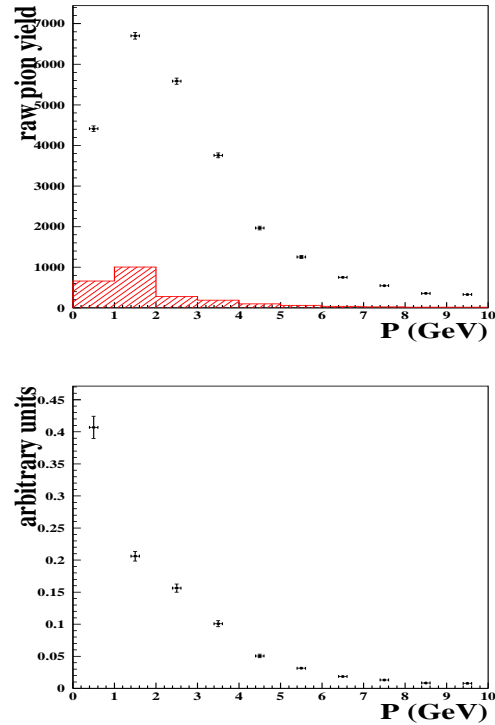


Figure 5. Upper; Raw pion yield. Lower; Yield corrected by pion correction factor, efficiency and acceptance. The red filled histo corresponds to the proton+electron background

7. M. Anfreville *et al.*, *Nucl. Instrum. Methods A* **481**, 339 (2002).
8. The CHORUS Collaboration, *Nucl. Instrum. Methods A* **349**, 70 (1994).
The CHORUS Collaboration, *Nucl. Instrum. Methods A* **378**, 221 (1996).
9. R. Frühwirth *et al.*, *Data Analysis Techniques for High-Energy Physics, second edition*. Cambridge University Press, Cambridge, 2000.
R. Frühwirth *et al.*, *Nucl. Instrum. Methods A* **262**, 444 (1987).

